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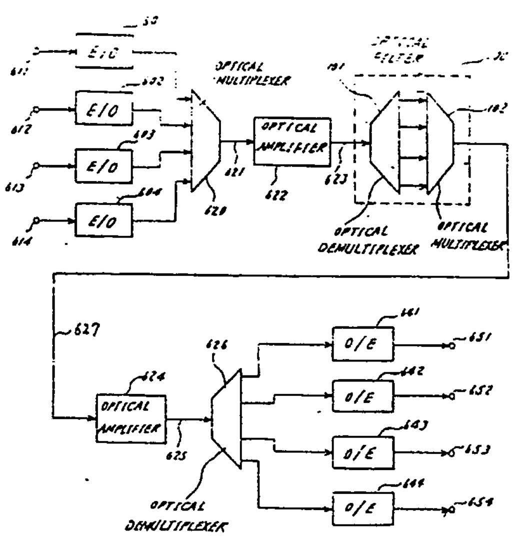
(54) **Optical-wavelength-division multiplex transmission system with an optical filter for spontaneous emission noise.**

(57) The invention relates to an optical wavelength-division multiplex transmission system comprising optical multiplexer means (620) for multiplexing a plurality of optical signals having different wavelengths into a wavelength-division multiplexed signal, optical amplifier means (622, 624) for amplifying said wavelength-division multiplexed signal from said optical multiplexer means (620) and optical filter means (100) disposed between adjacent ones of said optical amplifier means (622, 624) for suppressing undesired spectra of the wavelength-division multiplexed signal from the optical amplifier means (622, 624).

Fig. 1



EP 0 242 802 A2

OPTICAL WAVELENGTH-DIVISION MULTIPLEX TRANSMISSION SYSTEM WITH AN OPTICAL FILTER FOR SPONTANEOUS EMISSION NOISE

BACKGROUND OF THE INVENTION

The present invention relates to an optical wavelength-division multiplex transmission system for transmitting information using a plurality of optical signals having different wavelengths.

A demand for an optical fiber transmission system has been increasing for transmission of a wide band signal such as video signals, and/or a large capacity signal through transoceanic links. In such an optical fiber transmission system, however, a distance between an electro-optical (E/O) converter and an opto-electrical (O/E) converter is limited due to a transmission loss in the optical fiber. In order to solve this problem, an optical transmission system has been proposed by J.C. Simon in an article entitled "Semiconductor Laser Amplifier for Single Mode Optical Filter", Journal of Optical Communications, vol. 2, pp. 5l - 6l, April l983 (Reference l). In the article, an optical amplifier is used to expand the interval distance by amplifying a single optical signal as it is. Since the optical amplifier produces spontaneous emission noise during amplification of the optical signal, Simon uses an optical filter to remove the spontaneous emission noise.

On the other hand, according to the fact that a single optical fiber can transmit a plurality of optical signals having different wavelengths, an optical wavelength-division multiplex (WDM) transmission system has been studied in which optical signals supplied from individual E/O conventers are combined into the single optical fiber for transmission of much information.

The WDM transmission system is also restricted in an interval distance between the E/O and O/E converters. Therefore, it may be also desirable in the WDM system to provide a laser amplifier to increase the light power, as used in the single wavelength system. However, it has been never proposed to use such a laser amplifier in an optical WDM transmission system.

On the other hand, the WDM transmission system has the problem that the optical amplifier used therein tends to be more saturated by the spontaneous emission noise and the optical signals transmitted to the amplifier than the optical amplifier used in the single wavelength system. Accordingly, unless the noise is suitably suppressed, the optical signal in the WDM transmission system can not be amplified satisfactorily. This problem has never been considered.

SUMMARY OF THE INVENTION

An object of the present invention is to provide a wavelength-division multiplex transmission system using laser amplifiers.

Another object of the present invention is to provide an optical wavelength-division multiplex transmission system using laser amplifiers and optical filters for removing spontaneous emission noise produced in the amplifiers.

The above objects can be achieved according to the present invention by a provision of a wavelength-division multiplex transmission system comprising optical multiplexing means for multiplexing a plurality of optical signals having different wavelengths into a wavelength-division multiplexed optical signal, optical amplifier means for amplifying, as a whole, the wavelength-division multiplexed optical signal supplied from the optical multiplexing means, and optical filter means arranged between adjacent ones of the optical amplifier means for suppressing undesired spectra of an output optical signal supplied from the optical amplifier means.

BRIEF DESCRIPTION OF THE DRAWINGS

The above and other objects, features and advantages of the present invention will become apparent from the following detailed description when taken with the accompanying drawings in which:

Fig. l is a schematic block diagram of an embodiment of the present invention;

Fig. 2A shows spectra of input light to an optical amplifier;

Fig. 2B illustrate a transmission characteristic of an optical filter;

Fig. 2C shows spectra transmitted by the optical filter;

Figs. 3 and 5 show other examples of the optical filter;

Figs. 4 and 6 are filter characteristics of the optical filters shown in Figs. 3 and 5, respectively; and

Figs. 7A to 7E are waveforms for explaining an operation of the optical filter shown in Fig. 5.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

In Fig. 1, electric signals at input terminals 611 to 614 at a transmission side are converted, by E/O converters 601 to 604, to optical signals having wavelengths λ_1, λ_2, λ_3, and λ_4 which are, for example, 1540 nm, 1545 nm, 1550 nm and 1555 nm, respectively. An optical multiplexer 620 multiplexes the four optical signals from the E/O converters 601 to 604 into a wavelength-division multiplex (WDM) signal which is sent to an optical fiber 621. The WDM signal undergoes transmission loss during its propagation through the optical fiber 621. An optical amplifier 622 amplifies the WDM signal to recover an original light power and then sent again to an optical fiber 623. The optical amplifier 622 may be a laser amplifier described in the aforementioned Reference 1 or a fiber Raman amplifier. An optical filter 100 functions to remove spontaneous emission noise from the amplified WDM signal. The optical filter 100 includes an optical demultiplexer 101 for demultiplexing the four optical signals having wavelengths substantially equal to the wavelengths λ_1, λ_2, λ_3 and λ_4 from the WDM signal, respectively, and an optical multiplexer 102 multiplexing the four optical signals into the WDM signal again. Thus, the optical filter 100 can selectively pass through only the optical signals having spectra of substantially λ_1, λ_2, λ_3 and λ_4. The optical demultiplexer 101 and multiplexer 102 may be an optical multiplexer/demultiplexer described in, for example, "Low-Loss Single Mode Wavelength-Division Multiplexing With Etched Fibre Arrays", Electronics Letters, Vol. 20, No. 17, pp. 685 - 686, August 1984 (Reference 2).

The WDM signal from the optical filter 100 undergoes transmission loss during its propagation along an optical fiber 627. An optical amplifier 624 amplifies the WDM signal from the filter 100 to compensate the transmission loss and then sends the amplified WDM signal to an optical demultiplexer 626 at a reception side. The optical demultiplexer 626 demultiplexes from the WDM signal the individual optical signals whose center wavelength are λ_1, λ_2, λ_3 and λ_4. The O/E converters 641 to 644 convert the these optical signals into the original electric signals and provide them at output terminals 651 to 654, respectively.

Figs. 2A to 2C are charts for explaining an operation of the optical filter 100 shown in Fig. 1. Spectra of the output optical signal supplied from the optical amplifier 622 are composed of spectra having wavelength near λ_1, λ_2, λ_3 and λ_4 and spontaneous emission noise produced in the optical amplifier 622. The light power of the noise is P_{n1} and its pectrum is uniform with wavelength.

A filter characteristic of the filter 100 has passbands whose center wavelengths are λ_1, λ_2, λ_3 and λ_4, respectively, as shown in Fig. 2B. Therefore, when the WDM signal having spectra as shown in Fig. 2A is supplied to the optical filter 100, the filter 100 provides at its output spectra shown in Fig. 2C. That is, the spontaneous emission noise except for portions around wavelengths λ_1, λ_2, λ_3 and λ_4 is removed by the optical filter 100. Since the noise is produced in each optical amplifier and accumulated along the transmission line, the accumulated total noise power may become higher than the signal level at an input of a subsequent optical amplifier. This results in an insufficient amplification of the signal light due to a saturation of the latter amplifier.

The optical filter 100 used in the present invention reduces the noise level to relatively increase the signal level at the input of the optical amplifier 624 and thereby enabling to extend the distance between the amplifiers 623 and 624.

It is preferable to arrange an optical filter between the optical amplifier 624 and the optical demultiplexer 626 to remove optical noise produced in the amplifier 624 for longer optical transmission.

Although the optical filter 100 shown in Fig. 1 is arranged downstream to the optical amplifier 622, the filter may be arranged upstream to the amplifier 622 with the same effect.

Fig. 3 shows the optical filter 100 in the form of Fabry-Perot interferometer. In Fig. 3, the Fabry-Perot interferometer comprises a pair of parallel reflecting mirrors 501 and 502 separated from each other by a distance ℓ. An input light passed through the reflecting mirror 501 is reflected by the mirror 502 and then by the mirror 501 and so on. The Fabry-Perot interferometer allows only the wavelengths λ_i (i = 1, 2, 3, ...) to pass through the reflecting mirror 502 as an output light:

$$\lambda_i = \frac{2n\ell}{i}$$

where n is refractive index of a material between the mirrors 501 and 502.

Fig. 4 is a graph showing a light transmittivity vs. wavelength characteristic. As is apparent from Fig. 4, the transmittivity periodically takes a peak value aat the wavelengths λ_j, λ_{j+1} and λ_{j+2}. The half-value width W can be represented by:

$$W = \frac{2\pi n\ell}{c} \cdot \frac{R}{1-R}$$

where R is a reflecting coefficient of the mirrors 501 and 502 and c is velocity of light. By selecting the value of R suitably, the transmitted spectra width is determined so that only around wavelengths $\lambda_j \sim \lambda_{j+2}$ having the peak transmittivity are passed.

Fig. 5 shows the optical filter 100 implemented by a Mach-Zehnder interferometer. The Mach-Zehnder interferometer comprises a glass substrate 1000, a Y branch 1002 formed thereon, a Y coupler 1005 also formed on the substrate and waveguides 1003 and 1004 formed between the Y branch and coupler. An input light coming into an end surface 1001 is branched by the Y branch 1002 to the waveguides 1003 and 1004. These two input light components are combined at the Y coupler 1005, interfere with each other, and apears at an opposite end surface 1006 of the substrate 1000 as an output light. When a length of the waveguide 1003 is different from that of the waveguide 1004, the output light differs in intensity depending upon the frequencies. The light having wavelengths λ_i or frequencies f_i (i = 1, 2, 3, ...) represented by the following equation is strengthened by interference:

$$f_i = \frac{c \cdot i}{2 \cdot \Delta L \cdot n}$$

where ΔL is a difference in length between the waveguides 1003 and 1004; f, a frequency of the input light; and n, refractive index of the waveguides. Transmittivity of this interferometer can be represented by:

$$T = k \bullet \sin^2 (2 \bullet \Delta L \bullet f_i \bullet n/c)$$

where k is a constant. Fig. 6 illustrates relationship between frequencies and transmittivity.

An operation of the Mach-Zehnder interferometer will be described with reference of Figs. 7A to 7E. It is assumed that the Mach-Zehnder interferometer type filter 100 has a frequency selectivity as shown in Fig. 7A and that frequencies of the optical signals are f_1, f_2, f_3 and f_4, respectively. When the WDM optical signal having spectra shown in Fig. 7B is supplied to the filter 100, it provides spectra as shown in Fig. 7C. As apparent from Fig. 7C, an average value of the noise is reduced by about 50% of that shown in Fig. 7B.

The noise suppression is enhanced by further arranging an additional Mach-Zehnder interferometer having a characteristic of Fig. 7D. An output spectrum thereof becomes as shown in Fig. 7E.

Claims

1. An optical wavelength-division multiplex transmission system comprising optical multiplexer means for multiplexing a plurality of optical signals having different wavelengths into a wavelength-division multiplexed signal, optical amplifier means for amplifying said wavelength-division multiplexed signal from said optical multiplexer means and optical filter means disposed between adjacent ones of said optical amplifier means for suppressing undesired spectra of the wavelength-division multiplexed signal from the optical amplifier means.

2. The optical wavelength-division multiplex transmission system as claimed in claim 1, wherein said optical filter means comprises interferometer means having predetermined pass-bands, said wavelengths of said optical signals corresponding to center wavelengths of said pass-bands of said interferometer means.

Fig. 1

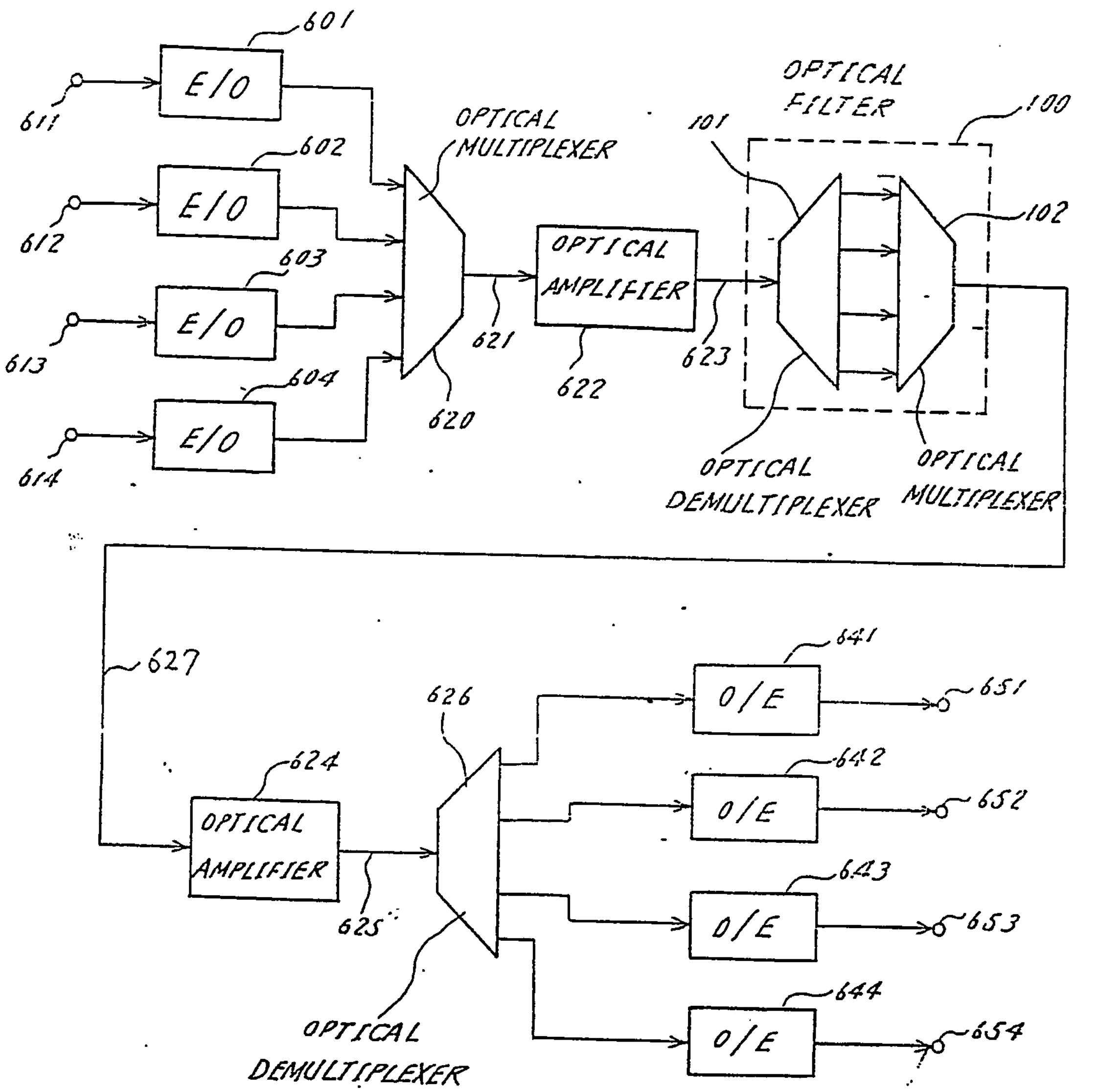

601
602
603
604
E/O
E/O
E/O
E/O
611
612
613
614
OPTICAL MULTIPLEXER
620
621
OPTICAL AMPLIFIER
622
623
OPTICAL FILTER
100
101
102
OPTICAL DEMULTIPLEXER
OPTICAL MULTIPLEXER
627
OPTICAL AMPLIFIER
624
625
626
OPTICAL DEMULTIPLEXER
641
642
643
644
O/E
O/E
O/E
O/E
651
652
653
654

Fig. 2A

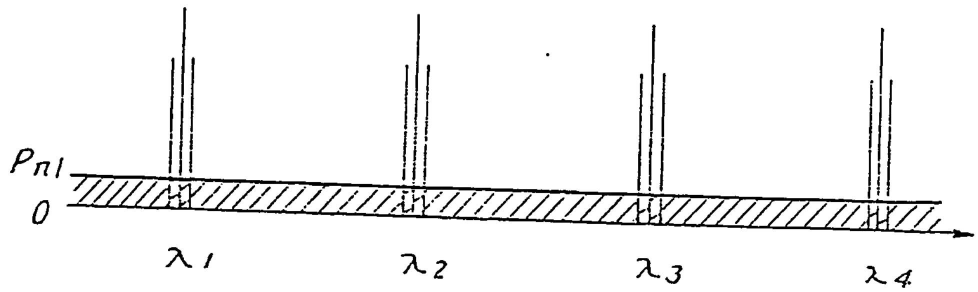


Fig. 2B

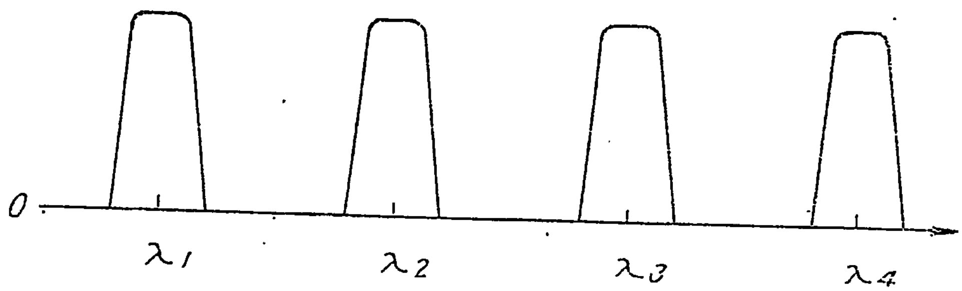


Fig. 2C

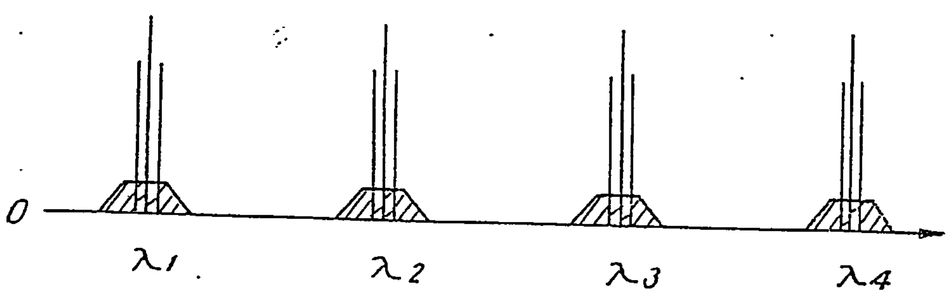


Fig - 3

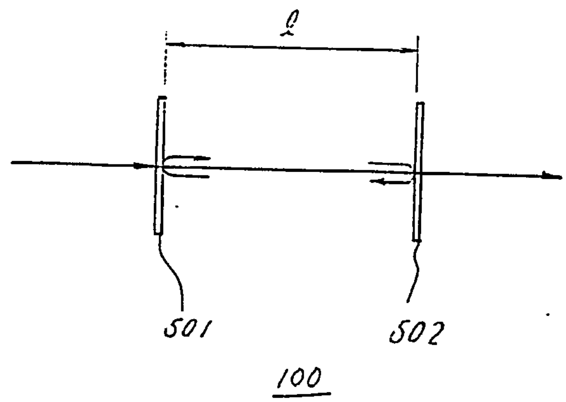


Fig - 4

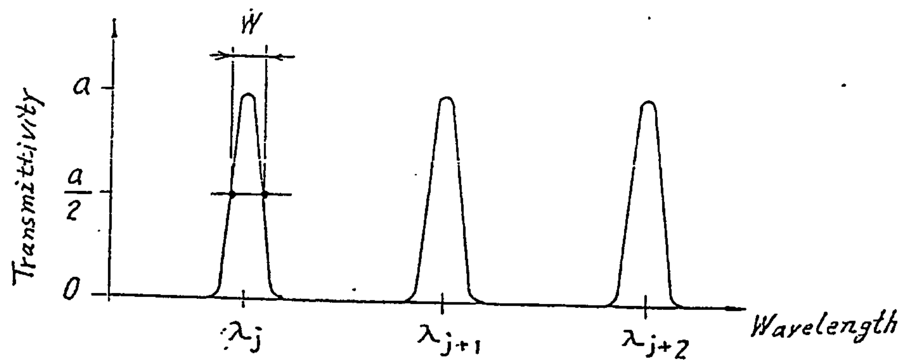


Fig-5

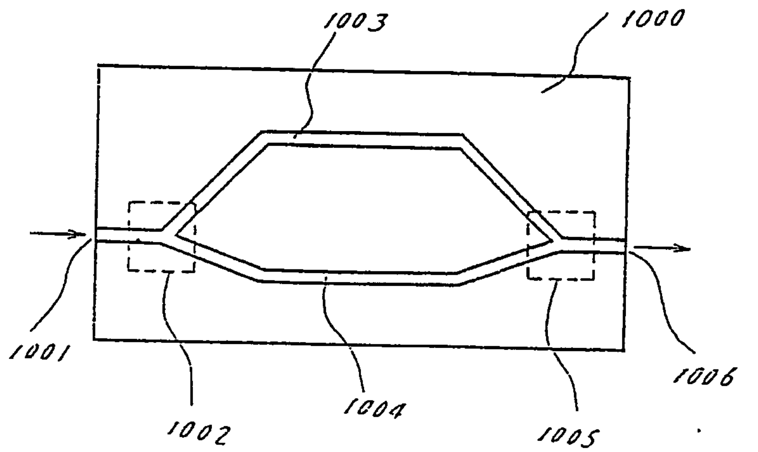

1003
1000
1001
1002
1004
1005
1006

Fig-6

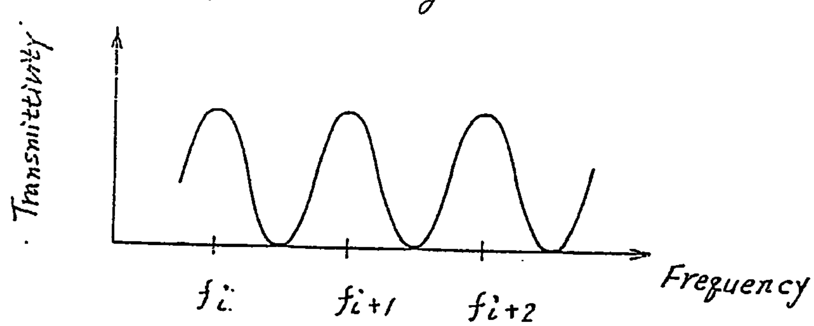

Transmittivity
Frequency
fi
fi+1
fi+2

Fig. 7A

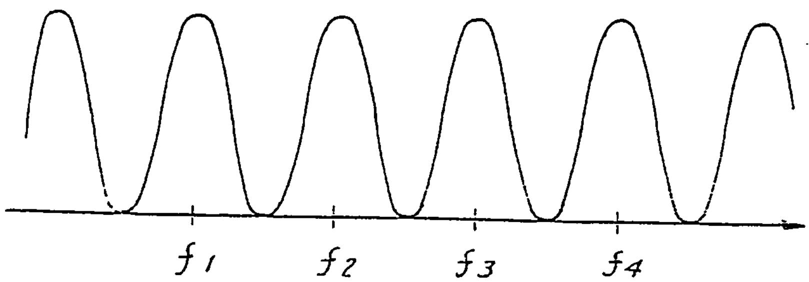


Fig. 7B

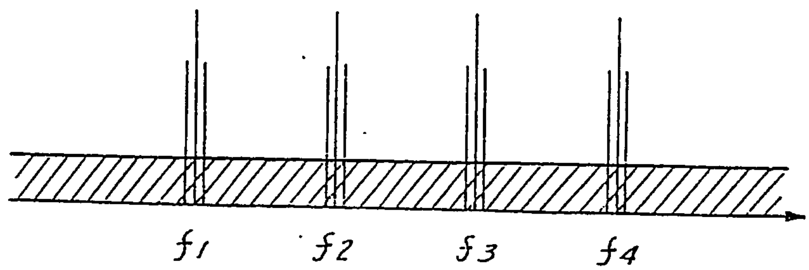


Fig. 7C

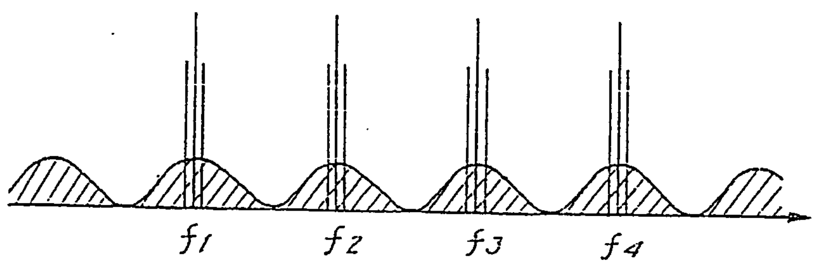


Fig. 7D

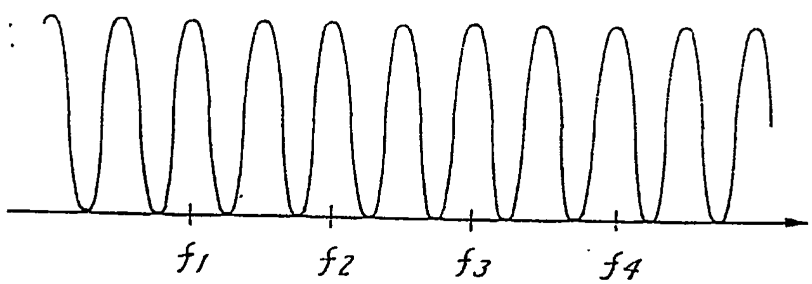


Fig. 7E